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A Study of
Elevated Railroad Structures

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A STUDY

OF

ELEVATED RAILROAD STRUCTURES

BY

AMBROSE GOULET GRANDPRÉ

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AMBROSE GOULET GRANDPRÉ

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OF Bachelor of Science in Civil Engineering

Ira O. Baker

HEAD OF DEPARTMENT OF Civil Engineering

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It would be difficult in a paper of reasonable length to treat fully a subject having so wide a bearing as that of elevated railroads. In view of this fact the following thesis will be limited to elevated railroads that carry municipal traffic only, and will not include such examples of elevated railroad work as the approach to the Merchant's Bridge at St. Louis or the four-track elevated structure of the Pennsylvania Railway at Jersey City. The purpose will be to give general types, their uses and advantages, rather than the details and dimensions of the various individual structures.

As the elevated railroad is one of the means for the achievement of rapid transit, it is particularly noteworthy just at this time on account of the activity of interest in urban transportation. Three of our eastern and two European cities have just completed extensive elevated systems. These five cities were facing problems of which every growing city will sooner or later meet a counterpart. Every lesson drawn from their experience may be of value.

People no longer desire to live in the congested heart of cities and are making every effort to locate their homes in the suburbs. The distance of these suburban homes from the business district is only restricted by the limit of travel as measured by time and convenience. The average man takes about thirty minutes to go to and from his work. He can live 2 miles away,

if he walks at the rate of a mile in 15 minutes. Horse-cars run about a mile in 10 minutes, which allows a distance of 3 miles. An average of all the Chicago cable lines gives a rate of 7.6 miles per hour, therefore in this example the workman could live about 4 miles off. The average Chicago electric car travels at 8.22 miles per hour, while the new 48-foot cars equipped with double trucks and air brakes make 9.25 miles per hour, which allows a circle of 5 miles radius for the homes of workmen, provided the city be furnished with the best cars and they run under the best circumstances. This is probably the limit for surface railways. The Chicago elevated trains make 14.3 miles per hour on the crowded loop, while one of the roads which uses the loop runs its local trains at 15.6 miles and its express trains at 20.0 miles per hour. If the workman lives 6 miles from his work and has the best surface electric transportation, he can cover the distance in 39 minutes; or by using the local elevated trains he will take 23 minutes, and by the express trains 18 minutes, the latter saving 21 minutes or 54% over the surface electric road. He could walk a mile to the station if necessary, save time, and get the exercise. From this it will be seen that there is an opening for an elevated road when the best surface lines take over 30 minutes in getting a man to his work; say in a city that begins to spread well out side of a circle of 6 miles radius or in other words the average city of 1,000,000 inhabitants. The operation of elevated roads as trunk lines giving express service, and the employment of surface lines as feeders through the use of a universal transfer, would give an ideal rapid transit system.

In order to secure rapid transit for large cities it is necessary to put up with some inconveniences and many predjudices. The character of the roads designated as rapid transit may be divided into three classes- underground, surface, and elevated. It is generally conceded that there are more difficulties in the way of building and operating the first of these and also more objections to it, than to the last.

Underground roads may be divided into two classes- deep level, and subway. Both are costly to build. Their cars are dark and require artificial light at all times. The ride is monotonous because there is no view from the car window, and because the constant noise in the underground passage is distressing to the passangers. On the other hand each type of underground road takes traffic from the street, so they are equivalent to widening it. When once built they cause no interference with surface traffic, and as they are out of sight they do not mar the appearence of the city. The deep level line is limited in its application by its excessive cost and by the difficulty of enlarging it; its comparatively great depth requires expensive lifts, and the bad air necessitates costly ventilating devices. Its good points are that it can be built wherever necessary, and that it does not interfere with surface traffic while being built, therefore having the advantage of the subway which practically stops surface traffic while under construction.

The surface road is fairly cheap to build. It has the benefit of natural light and ventilation. The view from the car is not monotonous. The speed is fairly great; and if the suburban trains of steam railroads, which run at about thirty miles per hour,

be included, it is 50% faster than the best overhead or underground railway. The surface street railway is dangerous because of the unprotected grade crossings of other lines, and because of teams and pedestrians on the street.

An elevated road must, and does, offer great inducements to get the people up stairs away from other means of transportation. This class of road is safe in that there are no grade crossings, except those controlled by interlocking plants, and also because the trains run above the street with less confusion and with no danger from teams and pedestrians crossing the tracks. The elevated roads usually have good terminal facilities in the business district, and thus leave the passangers close to their destination. It has speed because of the fewer stops; and also because the long trains give greater headway with the same capacity, therefore there is less danger from collisions when running at full speed, the express service used during rush hours being very speedy. Comfortable cars and waiting rooms are points in favor of elevated lines as is shown by the fact that their business is about 50% greater in the winter than in the summer. This type of road does not interfere with other traffic when in operation, and only slightly while being built. The view from the car is cheerful as compared with underground roads. The car is well supplied with natural light; and the ventilation is good. These advantages, at the least possible cost offer the best solution for many rapid transit problems, and hitherto they have not caused the elevated railroad to receive the amount of attention it deserves. Many objections have been urged against these roads, but they are more than balanced by the increased facilities. A British author even goes so far as to give the petty reason that

"for Londoners it possesses the fatal objection that the occupants of the cars as they pass along can look into the front windows and spy upon the occupants of the houses passed" Some of the real objections to elevated roads are; shutting off light from adjacent buildings; the great noise; the dripping of rain and melting snow upon the passers-by below; the danger of falling sparks, tools or other objects; the unsightliness of the structure as it is ordinarily built; and its injury to the architectural effect of buildings. Most of these objections can be overcome as will be seen in the following pages.

H I S T O R Y .

The idea of running passangers coaches on a single elevated rail originated about the middle of the ninteenth century, although the elevated rail had been used previously in the transportation of coal in the mining districts of England. The center of gravity was below the rail; but this plan differed from the modern aireal monorail line now in operation in Europe, in that the cars stradled the track instead of being suspended from it. This old idea was kept alive for a long time and seriously advanced as a scheme for city traction, and it was not until the middle eighties that all hope of making it a success was given up.

The first mention of elevated roads, as we know them today was made in 1867, when an elevated line was in operation in New York City, the tractive power being supplied by a wire rope that was pulled by a stationary engine. The first notice taken of them in Poor's Manual is made in 1873 when 3.5 miles are listed as being in operation in New York City. It did not take long however for the scheme to prove its worth, for in the course of a few years there were roads on four avenues in New York City, and they were under construction in Brooklyn.

It is curious to note how the same general type spread from city to city, and from road to road with some improvement on each new structure. Having started in the east, eastern ideas were brought to Chicago by Mr. R. J. Sloan. The first radical departure from the previous type was made by Mr. J. A. L. Waddell, who did

much for the improvement of elevated road construction when he introduced the use of the braced tower.

Europe caught up the idea when Liverpool saw the chance to put in the new form of rapid transit along her busy docks, and thereby keep the cars out of the way of the drays on the surface. Although Liverpool copied in a general way the American "standard" type of road, she had the honor to be the first to use electricity for power. Within the last few years both Berlin and Paris have completed fine examples of elevated roads which are constructed on entirely new lines, thus showing that European engineers are much interested in the advancement of this means of rapid transit.

The early history of each individual pioneer American road bears a remarkable similarity to the history of every other road of its time. This similarity lies in the number of damage suits that were brought against them, the financial troubles they experienced, the foreclosures by bondholbers, and the organization of new companies after receivers had been appointed to look after the affairs of the old ones.

The introduction of electric traction by motor cars instead of the "dummy" locomotives which had formerly been used, did wonders in placing the roads on a sound financial basis. The chance to use a cheaper grade of coal under the stationary boilers in the power house, and the elimination of a large number of firemen with the passing of the locomotive, made it possible for one road to haul by electricity 68,486 persons at a cost of $585.00 as against the hauling by steam of 36,525 persons at a cost of $562.00, thus increasing the number of passengers 87% while the cost of haulage increased only 4%.

An important factor in the success of Chicago elevated roads was the completion of the Union Loop in 1897. It had a marvelous influence for good on the tenant roads, for within a very short time their traffic had increase about 50%. This little railway, but two miles long, in the heart of Chicago, is one of the most remarkable railroad properties in the world. It is said to consist of a franchise, a power house, an elevated structure 11,150 feet long, eleven passenger stations, and an interlocking and signal system. Its ability to handle crowds is wonderful; on one occasion 67% of the track was covered with moving trains, 4,842 cars were passed over its tracks in an hour, and each one made the trip of two miles with eleven stops in less than fourteen minutes. Its existance is the main reason why Chicago now has about 100 miles of tracks resting on elevated structures, which give rapid transit service to all parts of the city.

Many incredible schemes have been advanced from time to time proposing to better the methods of building elevated roads. Some of the "ideal" roads were to be placed from 60 to 120 feet in the air, with spans of from 220 to 330 feet, so that they might pass over all existing buildings and thus save large right-of-way costs. Some schemers proposed truss spans, while others suggested suspension spans; some used heavy steel towers, while others thought of sky-scraper buildings for their columns, the station was to be on the roof and the elevator would be used to carry passengers up and down. Luckily for the life-insurence companies these idealists never even secured franchises.

C L A S S I F I C A T I O N .

Elevated roads may be classified according to:

1. Number of columns used to support the track;
2. Methods used to provide for the horizontal thrust of braked trains;
3. Methods which eliminate the general use of girders.

DESCRIPTION OF TYPE FORMS ACCORDING TO THE NUMBER OF COLUMNS USED.

Roads which are classified as to the number of columns used may be subdivided into:

(a) One Column
- single track located
  - on the curb line.
  - in the center of the street.
- double track.

(b) Two Columns Located
- under centers of supported tracks.
- just outside of surface-car tracks.
- on curb line.

(c) Three Columns.

(d) Four Columns.

(a) ONE COLUMN. The single column structure has a heavy post securely anchored to a solid foundation which supports, by means of a flared top, two or more longitudinal girders and these in turn carry the track. The road may consist of a single line of columns planted on the axis of the street, perhaps between the tracks of a surface road, or it may consist of two such rows of columns, entirely independent, that are set on the curb line. Since there are no connecting braces to cross the street, this type is not massive and does not shut off the light as much as do some of

the following types. This type is shown in Fig. 1. which was taken from a model in the Civil Engineering Museum of the University of Illinois. A single-column road has been built that carries two tracks, see Fig. 2. The eccentric loading in this road is excessive, and the supporting post is necessarily very heavy and rigid.

Fig. 1.

(b) TWO COLUMN. The double-column road is the type most often used. When the road is laid out on a street having surface lines, there are two possible locations for the columns supporting the elevated structure: either they may be close together, just allowing enough space between them for the clearence of surface cars, as is shown in Fig. 3; or by extending the transverse girder they may be set on the curb lines. The choice of either of these two types will depend on the franchise of the company. The former impedes traffic more, but it cuts off less light from the shops than

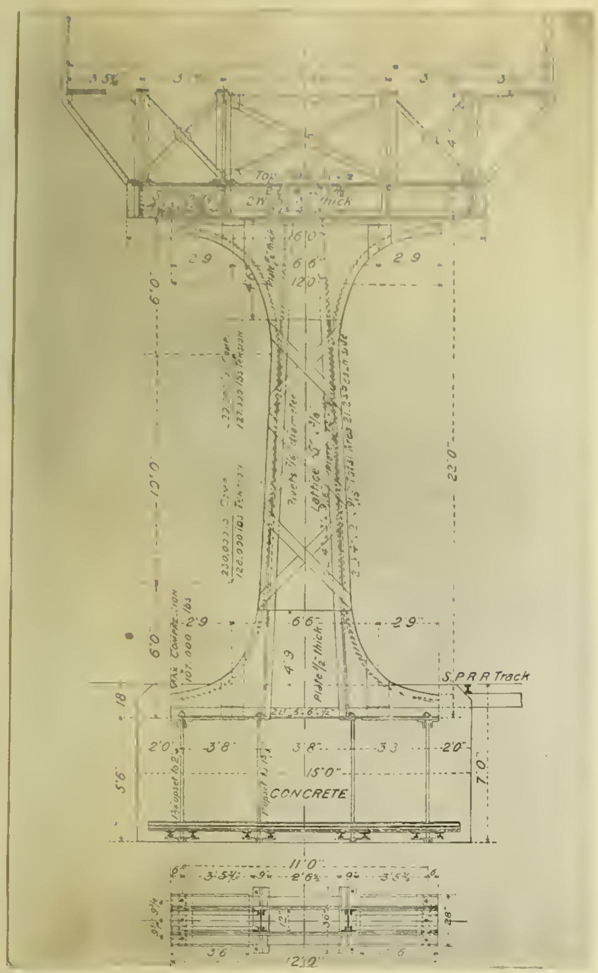

Fig. 2.

the latter; then too Mr.J.A.L. Waddell in his investigations found that the type with the columns closest together cost 12% less on tangents than did the other. A double-track road with its columns set near the center of the street has its longitudinal girders attached to simple transverse girders that span the distance between the columns; while a four-track road that has its columns in a similar location has to use cantilever transverse girders in order to obtain the necessary width for four tracks, as in Fig. 4. When the line owns a private right-of-way, the columns are generally placed directly beneath the center lines of the tracks, which eliminates the large bending moments found in the preceeding types of two-column roads, because the center of the load is applied just above the support, see Fig. 5.

(c) THREE COLUMN. The three-column structure is seldom used in new work. It finds its utility in the reconstruction of old two-track roads that are supported as shown in Fig. 5. Here, if it is found necessary to add a third track for express service a third column may be placed alongside of the other two, and the new track with its longitudinal girders may be added.

Fig. 3.

(d) FOUR COLUMN A four-column road is used to support four tracks. This type is seldom employed except on private right-of-way, because the numerous columns and foundations leave no room for the passage of surface traffic. Each track is carried by a column which is placed directly beneath its central line. The longitudinal girders are located almost vertically below the rails, and are supported, one on each side of the column, by short cantilever brackets. This construction as it is shown in Fig.6 is more rigid than the four-track structure carried on two columns as shown in Fig. 4. The former type is a little

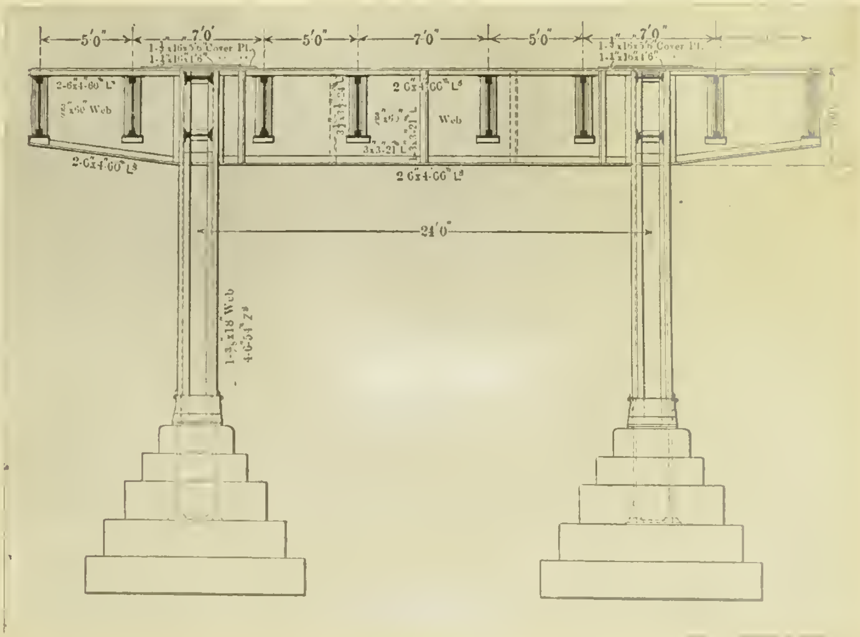

Fig. 4.

more expensive, however, because of the number of foundations required, although the metal work itself is considerably cheaper in the latter case.

Fig. 5.

DESCRIPTION OF TYPE FORMS ACCORDING TO THE METHODS USED TO PROVIDE FOR THE HORIZONTAL THRUST OF BRAKED TRAINS.

The next notable feature that divides these structures into types is the various meth-

Fig. 6.

ods used to economically transfer to the ground the horizontal thrust of braked trains. The amount of this thrust is a subject of dispute among engineers. It will be considered later in the discussion of loading. Three methods are now in use to transmit to the ground this longitudinal thrust:

(a) Braced Towers.

(b) Columns Braced by Arching Lower Chord of Longitudinal Girder.

(c) Masonry Piers.

(a) BRACED TOWERS. Mr.J.A.L.Waddell was the first to use the braced tower as it is shown in Fig. 7 in the design of elevated railroads. This design is especially applicable to roads running on a private right-of-way, because the towers braced both longitudinally and transversely cut off all passage ways under the structure, and therefore if the structure were built over the street would stop all surface traffic. These towers are so placed that they occur every third or fourth bent. Since they are braced in both directions, their use relieves the columns of all lateral strains and thus permits them to be of smaller

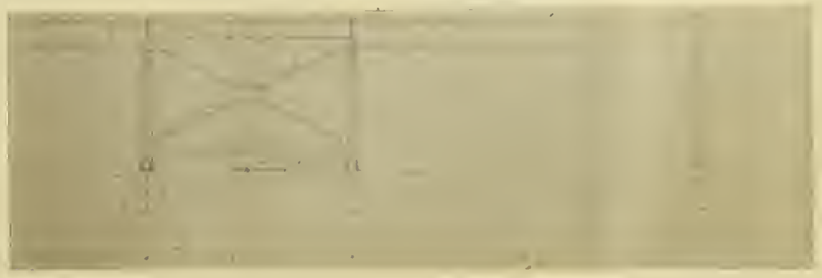

Fig. 7.

section than they would be otherwise. This saving in the columns more than makes up for the extra material in the braced towers, the total saving on a four-track structure on tangents being 9%. This construction is very rigid at curves as the braced towers take up all stresses due to centrifugal force.

(b) ARCHING LOWER CHORD. The idea that the street area obstructed by massive foundations should be a minimum has introduced another type of elevated road which transmits directly to the ground the longitudinal thrust of braked trains. It was found that the structure vibrates less if the lower chord of the longitudinal

Fig. 8.

girder were carried down to the ground; because this construction avoids the weak spot at the junction of the longitudinal girder and the post that is found in ordinary elevated railroad construction. This type, shown in Fig. 8, is of cantilever construction, consisting of an arched portal superstructure with projecting arms, the extreme points of which are connected by suspended girders to similar points on the next cantilever. The structure may be compared to a number of tables, the intervals between which are spanned by suspended platforms. The use of the arch shape makes it unnecessary to anchor the posts with expensive foundations, the weight of the structure being sufficient to hold it in place. In sections of this road where it is not over the street, the posts are inclined

transversely outward toward the bottom to give greater rigidity to the structure, see Fig. 9.

(c) MASONRY PIERS. Masonry piers have been used on one European road to take up and transmit to the ground the horizontal thrust of braked trains. The ordinary supports in this case are ornamental cast-iron columns, a material not well adapted to resist bending stresses. As the spans are very long, trusses are used instead of the customary girders. This construction does not seem to be very economical, and was probably adopted chiefly for its beauty. This road passes over the parking of a boulevard, and the piers, which occur every third or fourth bent, fall on each side of the intersecting streets, thus forming what appears to be the pillars of a gateway.

Fig. 9.

DESCRIPTION OF TYPE FORMS ACCORDING TO THE METHODS USED TO ELIMINATE THE GENERAL USE OF LONGITUDINAL GIRDERS.

(a) Masonry Arches.

(b) Retaining Walls and Earth Filling.

(a) MASONRY ARCHES. A series of arches has been used to support an elevated railway where the company owned a private right-of-way. The structure would be almost impossible on any out private property where there are no intersecting streets, because the rise of the arch, which could not ordinarilly be very great, would make it difficult to obtain the necessary openings for street crossings. The operation of trains over such a structure would make much less noise than their operation over any of the foregoing types, since there would be practically no vibration.

(b) RETAINING WALLS WITH EARTH FILLING. If an elevated railroad company owns a private right-of-way, it might support its tracks on a structure consisting of concrete or masonry retaining walls with the necessary earth filling. This type of construction has never been used however, because besides the difference in cost of the walls and filling, as compared with the cost of steel, the purchase price of the right-of-way enters the question. The right-of-way for an elevated road is ordinarily obtained at a fairly low cost, because the sale is subject to the condition that the elevated railroad company will not cut off the access of property owners from the rear; but with the type of road here under consideration the cost of the right-of-way would be greatly increased, if it were not made prohibative. The difficulty of crossing inter-

secting streets could be overcome by spanning them with girders as is now being done in track-elevation work. This type like the proceeding one would be practically noiseless and therefore very acceptable.

D E T A I L S O F C O N S T R U C T I O N .

LOADS.

The designer of a structure, before he can procede with the detailing of any of the parts, must first determine the loads and stresses to which it will be subjected. In elevated road design the following loads are considered:

(a) Live Load.

(b) Dead Load.

(c) Wind Load.

(d) Traction Load, or the Thrust of Braked Trains.

(e) Centrifugal Loads on Curves.

In the design of one of the Chicago roads the following values were given to the above loads.

(a) LIVE LOAD. Every car is equipped with heavy motors operated by a multiple control system from the head of the train. This gives about the heaviest car found in elevated road practice, a 48-foot car weighing 57,000 pounds empty, and when carrying 100 passengers at 150 pounds each the loaded car weighs 72,000 pounds. In the case refered to above the weight of the loaded car was assumed to be 80,000 pounds, which makes a train of the usual five cars weigh 400,000 pounds.

(b) DEAD LOAD. The dead load for a single track was taken as 420 pounds per linear foot for the track system, and 360 pounds per linear foot for the standard 50-foot plate girders, making a total dead weight of 600 pounds per linear foot to be supported by the columns.

(c) WIND LOAD. Wind loads do not play as important a part in the design of elevated roads as they do in ordinary steel construction. The elevation is small and the road is sheltered from the wind by the surrounding buildings. These loads are considered rather in order to provide for the lateral thrusts due to swaying trains, which now in the day of electric traction are rather small. The allowance usually made is 30 pounds per square foot of exposed surface, both fixed and moving; but is considered only in the design of the lateral systems of the longitudinal girders.

(d) TRACTION LOAD. The amount of traction load, or that due to the thrust of braked trains, is a subject that has called forth a number of widely varying views from prominent engineers. In the Chicago road under consideration it was claimed the traction load was 20% of the live load. This is said to be too high, because the wheels do not skid, and this seems to provide for such a condition. Some of the determining factors are: the speed of trains, the solidity of the floor system, the number of bents between expansion joints which break to a certain extent the continuity of the structure, and the number, position, and condition of trains. On a road that has expansion joints at every column, a movement of a quarter of an inch was noticed 700 feet away from the braked train, and probably the movement extended several hundred feet more before becomming entirely unnoticable. The observer who was an experienced man estimated that about forty columns were stressed by the braking of the train. Since the cars on this road are 48 feet long, and the standard girder is 50 feet in length, each column carries the weight of a single car; and if the horizontal thrust on a column due to a single car, which is taken to be 20% of

80,000 or 16,000 pounds, were to be applied at the top of the column, it would be torn from its foundation. Nevertheless this structure still stands and is in excellent condition. Probably the use of 5% would be better than 20% of the live load as the amount of the thrust due to braked trains. In defence of the latter however it may be said that if on a four-track structure two trains going in one direction are stopping, and simultaneously two others going in the opposite direction are starting, all traction forces are cumulative and would form an immense force, which might probably warrant the use of 20% of the live load as the horizontal thrust due to the traction forces.

(e) CENTRIFUGAL LOADS. The centrifugal loads on curves are taken care of by the usual formula. They are considered only in the design of the lateral systems of the girders, because the columns are strong enough to withstand the transverse stresses induced by the trains rounding the curves.

FOUNDATIONS.

Every road after it has adopted a standard has to make special designs for many of its foundations, because of local conditions such as gas or water mains close to the surface, soft ground, quicksand, and the many unknowns that are hidden beneath a street pavement or under the surface on old building sites which are frequently in the route of a new road. As a general average a foundation may be expected to carry 120,000 pounds. If the space is limited, or if the soil be poor, as on a water-front, piles are often required under the pier proper; and sometimes, as when crossing an ancient water-course, concrete in wells has been employed as

underpining.

Under ordinary circumstances the foundations vary from 7 to 9 feet square, and from 7 to 10 feet deep, see Fig. 10. In the older types either brick or stone masonry was used, and generally consisted of a footing course made of large dimension stones, usually 12 inches thick, on which rested two slabs that covered the footing course and served as plates to hold the heads of anchor bolts. Then came a truncated square pyrimid of either brick or stone, top-

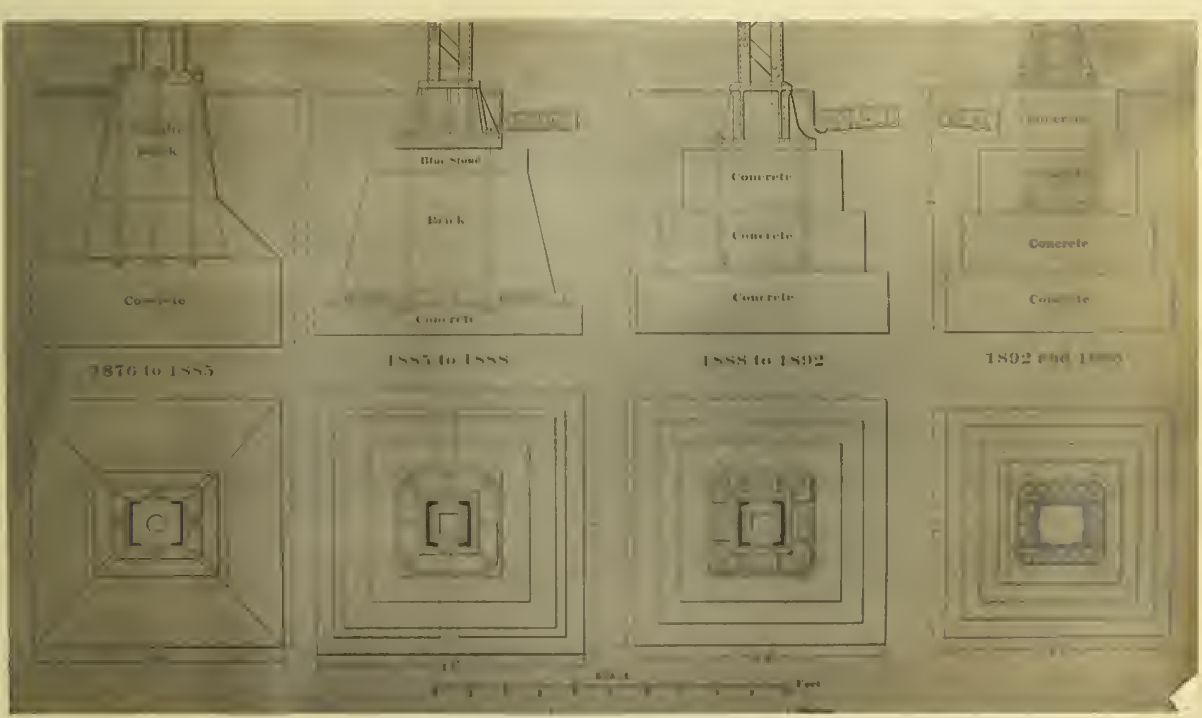

Fig. 10.

ed by a single block for a coping. The modern construction is entirely of concrete. There is a footing course as before, and then either a truncated square pyrimid, or a number of courses diminishing in size toward the top, the whole being capped with a coping level with the ground surface. In the lower courses is embedded a base-plate casting that holds the heads of either two or four anchor bolts as the design may require.

COLUMNS.

The proper design of the columns is one of the most essential features of a good elevated-road construction. More metal is required to resist the horizontal thrust of braked trains than is needed to support both the dead and the live loads. It is not known exactly how this horizontal thrust was treated in the design of the early roads, but it is a fact that these roads had columns that were far too heavy, therefore every advance in the economical treatment of the longitudinal forces causes a great saving of metal.

There are four types of columns:

(a) Those free at both ends.

(b) Those free at the top and fixed at the bottom.

(c) Those fixed at the top and free at the bottom.

(d) Those fixed at both ends.

(a) Columns free at both ends are seldom used in elevated road construction. The type gives no stiffness to the structure, and could only be used in a road where every third or fourth bent is a steel tower, a masonry pier, or other device giving ample provision for the horizontal thrust of braked trains. The European road using ornamental cast-iron columns and an occasional stone pier, could be designed to come under this type, if it were found difficult to rigidly fix the columns at the ends.

(b) Columns free at the top and fixed at the bottom are the general type in the older roads. In these the girders merely rest on the column, or are but slightly riveted to its top, which is flared out to a width sufficient to span the distance between the two girders that support the track. At the bottom the column is securely anchored to a heavy foundation. Any horizontal thrust

that may be transmitted from the girder to the column, has a lever arm that is the full length of the upright. This sets up the highest possible bending stresses in the post.

(c) The road having columns fixed at the top and free at the bottom, resembles a series of four legged tables. In this type the top of the column is rigidly attached to the web of the transverse girder, which in turn is riveted by its web to the ends of the track girders; at the bottom the column merely rests on the pedestal that caps the foundation. This type, like the preceeding one, permits the longitudinal forces to act on a cantilever arm which is the full length of the column.

(d) Columns fixed at both ends belong to the more modern construction. The lever arm is reduced to one half of its length in the two proceeding types, and this of course reduces the moments and consequently the metal necessary to resist the stresses due to bending moments. However, complicated design and the necessary heavy details at both the top and bottom, together with the difficulties of manufacture and erection, tend to counterbalance any saving of metal in the column itself. Time only can tell whether it is good policy to make a metal elevated-road structure as rigid as this type is, in preference to one that has some provision for slight vibration, as have the two preceeding types. A steel elevated-road structure is comparatively light, and therefore must vibrate; but in a road with the columns fixed at both ends no vibration can take place without overstraining some detail. What detail is going to fail first?

The road that uses girders with an arched lower chord extending to the cap of the foundation has a very light column. The

same is true of the road that employs braced towers. In both these cases no further provision has to be made for the horizontal thrust of braked trains; and therefore the principal duty of the post is to support the vertical dead and live loads, a stress that requires much less metal to resist it than does the bending stress which is so often thrown on the column.

PEDESTALS.

The pedestal or base of the column is designed to make the column and the foundation continuous, for roads that have their columns fixed at the base; and in roads that have their columns free at the base, the pedestal affords a proper bearing for the column. The base that gives fixidity may be made in either of two ways: first by a heavy casting, or second by a combination of plates and angles.

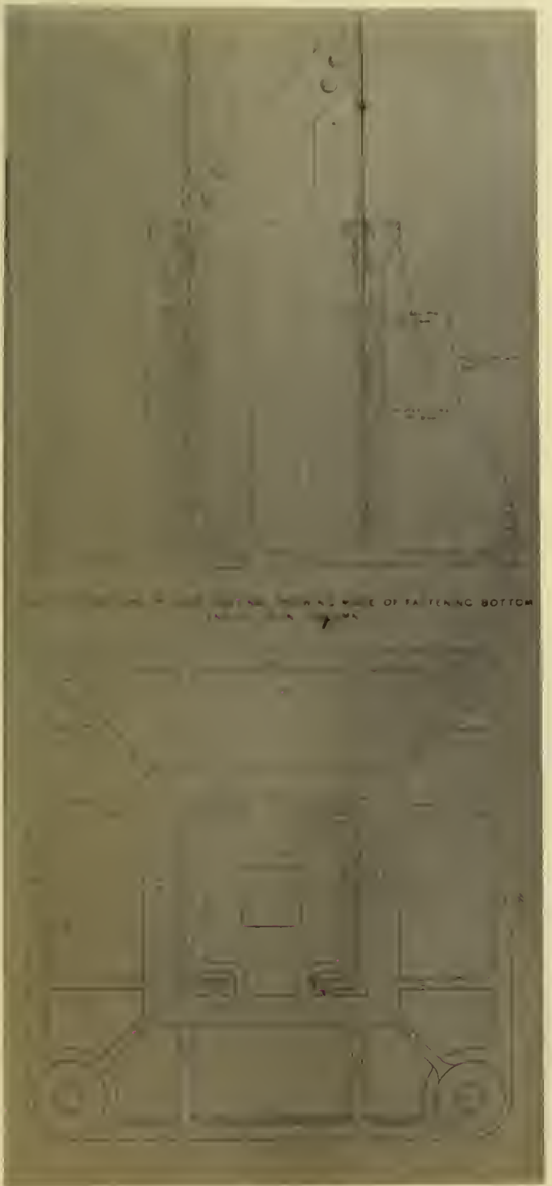

Fig. 11.

The use of a casting is the older method, and as generally built consisted of a heavy casting, in some cases weighing as much as 1,900 pounds. This casting contained deep sockets, see Fig. 11, made to receive the base of the column, which was sometimes held in place by wedges and pins, but more

often by a cement consisting of iron filings and sal ammoniac, a combination commonly called "rust cement". In the base of the casting are two or more holes made to receive the ends and hold the nuts of the anchor bolts.

The more modern roads use a base which is made up of plates and angles. The foot of the column is reinforced by plates and these are attached by angles to the foot or base plate, which give a sufficient bearing area. At present there are two methods of fastening this style of pedestal to the foundation by means of anchor bolts. Either the bolts are merely passed through holes near the edge of the bed plate and capped by a nut; or the bolts are made longer and are enclosed in a curved steel plate, which is made long enough to contain an ample number of rivets for fastening it rigidly to the column, and which has a squared and smooth top to receive a heavy washer plate that presses against the nut. This last gives a much more rigid connection than the former.

The base casting admits of a neater construction, but the superior anchorage and economy afforded by the more recent type of column base outstrips this feature. Either type may be covered by a fender casting, if necessary to protect the pedestal from the blows of wheels, see Fig. 12, and to keep out the moisture and dirt of the gutter or street surface. It is the general practice in all other

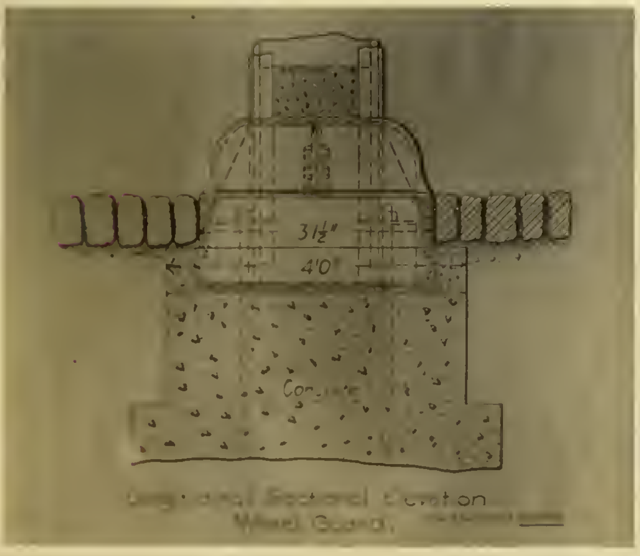

Fig. 12.

cases to fill all hollows and crevices with cement mortar that is well smoothed off on top so that it will shed all water and keep out all refuse that would gather moisture about the base of the column.

The most unique pedestal that makes no attempt to obtain fixidity for the column base, is the one used by the European road in which the lower chord of the longitudinal girder is arched down till it meets the base of the column. Here the column terminates at the foot in a cast-steel shoe, that has in the bottom a hemi-spherical cavity, which fits a globular projection on the steel casting that caps the foundation. There is no anchorage, the weight of the structure being sufficient to hold it in place.

CROSS SECTION OF COLUMNS.

A number of different cross sections have been used in the design of columns for elevated roads, a few of which are shown in Fig. 13. The cross section shown in cut a was in common use in the early roads; it was made of wrought iron and was known as the six-segment Phoenix Column. Cuts b, c, and d show sections of columns made up of channels and lattice bars. The one marked b is the easiest to manufacture, but the columns c and d are better adapted for roads that have their posts in the street. A column with the cross section shown in cut d is especially adapted to withstand the blows of passing wheels. The cross sections shown in e and f are noticable because of the special shapes used. The channels in e have round corners that were used for self protection and their neat appearence; cut f shows a cross section where "bulb" angles were used, probably for the same reasons. Cuts g and h show columns well designed for use in the street where they are likely to be

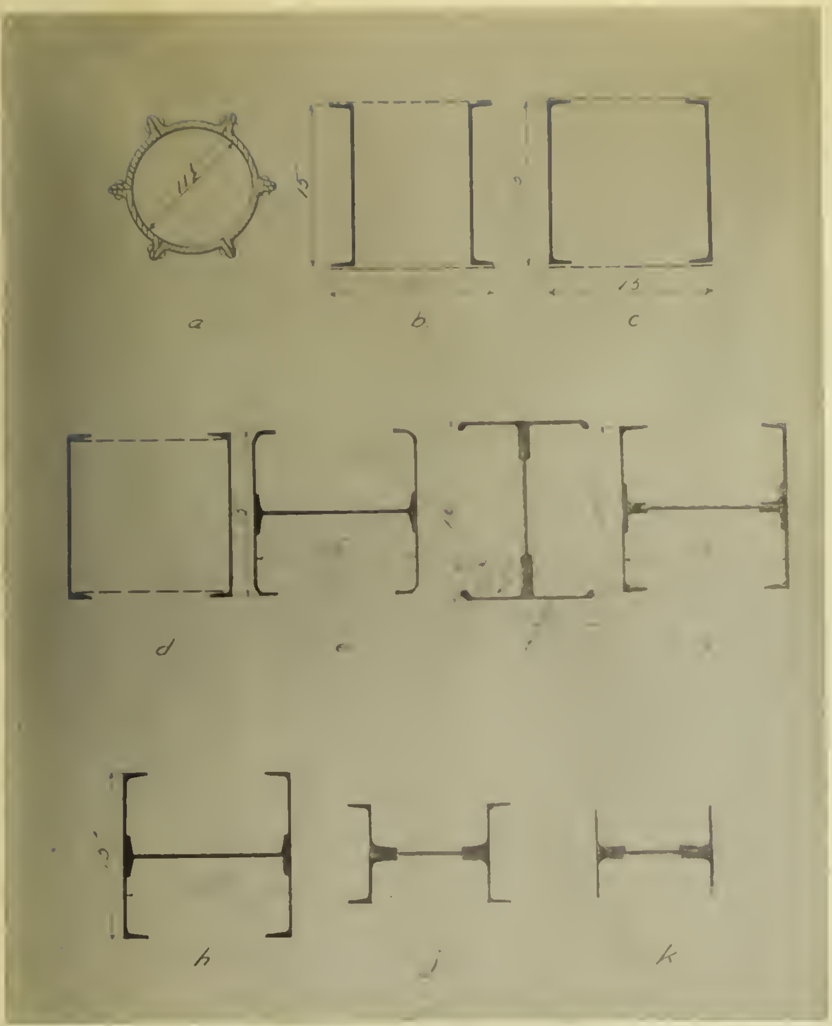

Fig. 13.

struck by passing vehicles; while cross sections j and k are better adapted for lines owning a private right-of-way, because they are easy to manufacture but are not well adapted to resist blows.

JUNCTION OF COLUMN TO GIRDER.

If the column is located under the center line of the track, there are two methods of joining it to the girders, depending on whether it is to be "fixed" or "free" at the top. The modern method to obtain fixidity is to use a column with the cross section shown in either j or k, and to prolong the angles or Z bars, as the case may be, above the level of the base of the track girders. The ordinary web of the column is cut off below the lower edge of the track girder, and a wide plate is placed between the angles or z bars, and is spliced to the ordinary web of the column, see Fig.14. This wide web is reinforced at the top and bottom with flange angles, and thus makes a small transverse girder to which the ends of the longitudinal girders may be attached.

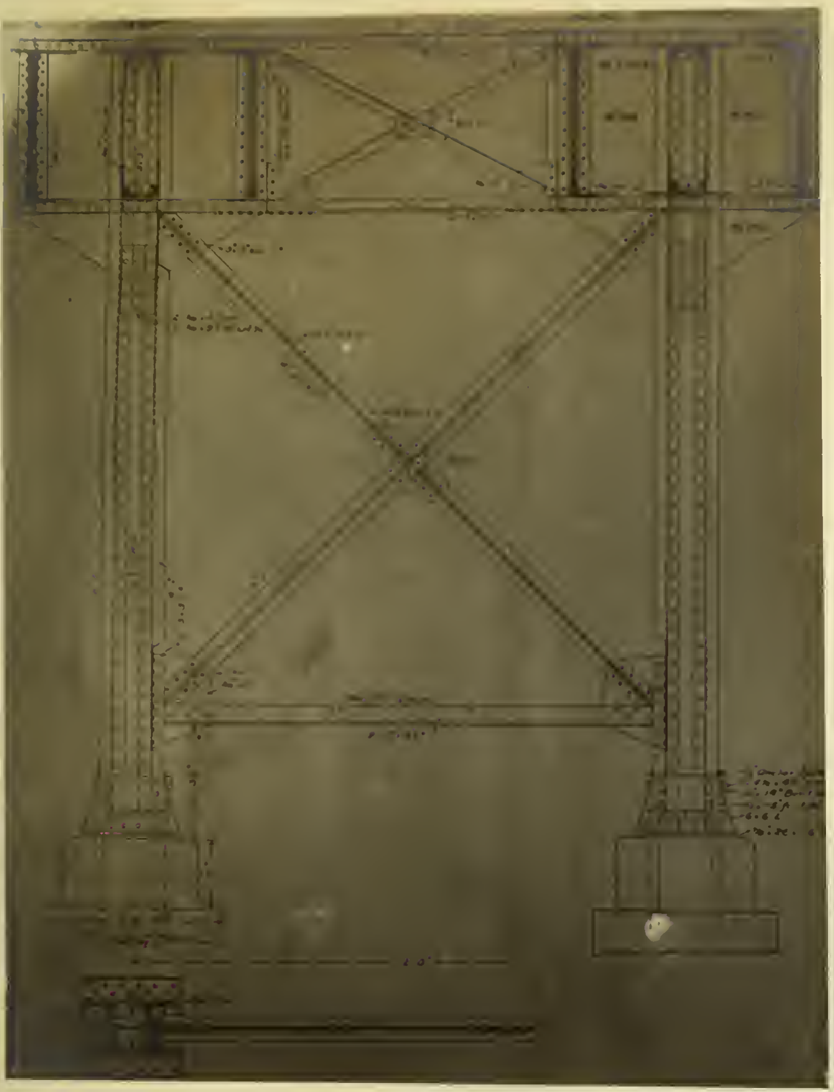

Fig. 14.

Sometimes the wide web plate that is inserted at the top of the column is spliced to the ordinary web at quite a distance below the level of the bottom of the longitudinal girders; and from this point the plate begins to spread out with an easy curve till it reaches the required width. Curved flange angles are placed on the lower edge of this web, this curved bracket giving the whole construction a very neat appearence.

If the column is placed under the center line of the track and there is no intention of having a rigid joint, then the column is flared out till it attains a width sufficient to support the two track girders, and is capped by a heavy plate which is joined to the web by angles, the bottom flange of the longitudinals being riveted to this bearing plate. If there is a desire to have a little stiffness at this joint, a knee brace or bracket is put on one side of the column, and connects with the longitudinal girder by means of a

stiff strut that is fastened to the webs of the longitudinal girders at a short distance in front of the column.

If the columns support a long transverse girder which in turn supports the track girders, as is shown in Fig. 3, page 14, the column is generally rigidly riveted to the transverse girder. In this case the web of the cross girder is rigidly attached to the column by means of angles and plates, and the ends of the longitudinal girders are securely fastened to the web of the transverse girder. Sometimes brackets are placed on one side of the column and are joined to the underside of the cross girder, and thus give stiffness to the structure.

TRANSVERSE GIRDERS.

Strictly speaking the elevated road that has its columns placed directly below the center lines of the tracks has no transverse girders, since the system of stiffeners which is placed between the track girders is really a system of sway bracing, see Fig. 15. It is the road that has to place its posts in other locations than under the tracks that has real need for transverse girders. Plate girders, lattice girders, or a combination of the two have been used for this purpose. Their function is to transmit the load

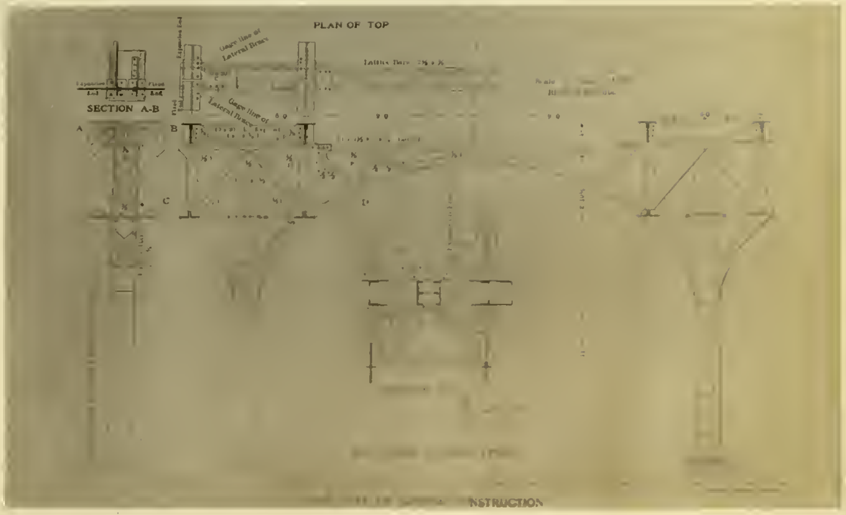

Fig. 15.

from the ends of the track girders to the columns. Sometimes they act as simple beams, sometimes as continuous beams, and in one case at least as cantilevers. Their connection to the column is always rigid, the style of connection used depending upon whether or not the cross girder is a simple beam. The type used in the road that has a simple beam for a cross girder has been described on page 31. Roads that have transverse girders that project on both sides of the column to which they are attached, may use either of two methods to join the girder to the column.

1. The first type of junction, which requires a column with a cross section similar to either f,j,or k of Fig. 13, consists in cutting off the web of the column at the base of the transverse girder and then splicing it to the web of the girder which is placed in the slot between the angles or Z bars ordinarily occupied by the web of the column.

2. The second construction places the transverse girder upon the milled top of the column, and connects the girder and the column by field rivets through the vertical connection angles on the girder web, and also through a pair of jaw plates shop-riveted to the web of the column and projecting up almost to the top of the girder.

3. Another method is to rivet a short simple girder between the columns, and then add a bracket to the opposite side of the column as a projection of the cross girder. This type is not as rigid as the two foregoing styles, and is hardly ever used.

Roads which use transverse girders are difficult to erect, the large amount of field riveting adding greatly to the task; and therefore such construction is generally used only where city ordi-

nances or special obstacles require it.

LONGITUDINALS.

Longitudinals may be divided into two very general classes 1, plate girders, which greatly darken the area below the structure; 2, open-web longitudinals, which do not interfere to such a great extent with the passage of light. All metallic elevated-road structures, except one, employ girders of one type or another as longitudinals; and all of these, but a single road, use deck girders.

The plate girders employed in elevated roads vary but slightly from those found in ordinary railroad construction. The

Fig. 16.

span is usually between 30 and 60 feet, with an average of about 40 feet. Computations have shown that the weights of equally well designed plate and lattice girders are about equal. The smaller cost per pound for plate girders gives this type the advantage; but city ordinances often require the use of lattice girders, especially along streets where light is a necessity in shops and stores.

Lattice girders of the Warren type were the first longitudinals used in elevated-road construction. Their poor design in the matter of shallowness, and the failure of the gravity lines to intersect at the panel points caused much trouble. The old type used no connection plates at the panel points, the angles being

riveted directly one to another. The modern type, which is on the lines of the Warren deck truss with verticals, uses plates at all intersection points, and has the gravity lines meeting at a common point. Heavy angles are placed vertically at the ends of the track girder, which connect it to the transverse girder (where the latter are used); or in the other type of construction these angles bear on the top of the column through the proper connections.

The two European roads that are unique are peculiar because of the types of longitudinals used. The one which uses a girder with an arched lower chord has been described on page 16 and is illustrated in Fig. 8. The other road uses trusses for longitu-

Fig. 17.

dinals, because even the shortest spans would require rather deep girders. These are pony trusses with straight lower chords and parabolic upper chords, the web members being arranged according to the Pratt system. They make a very beautiful structure, the succession of parabolic curves being a very pleasing sight as compared with the straight lines of the ordinary elevated-road structure.

EXPANSION JOINTS.

The proper design of joints which will provide for the expansion or contraction of the metallic structure, is no easy problem

in the planning of elevated roads whose columns are fixed at the top. One great trouble is to avoid large eccentric loads on the top of the column; another difficulty is to determine the proper number of bays between expansion joints, because a large number of joints breaks up the continuity of the structure, while a smaller number causes large bending moments in the columns due to the thrust of the expanding metal in the track girders, which in turn cause large stresses in the extreme fibres of the column. Computations which have given proper attention to these stresses and to the fixidity of the ends of the columns, limit the distance between expansion joints to 150 feet, or one such joint to every fourth or fifth column.

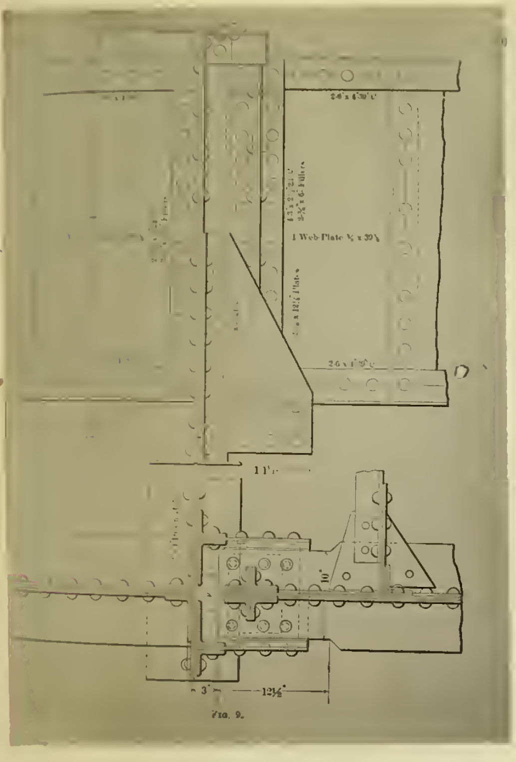

Fig. 18.

The common style of expansion joint, Fig. 18, is formed by making a pocket which is shop riveted to the web or stiffener angles of the transverse girder. These pockets are constructed with vertical side plates connected at the bottom by a short piece of channel or I beam riveted to both plates, and thus form a seat for the loose end of the longitudinal girder. The girder is kept from tipping sidewise by being snugly fitted into the pocket, while the top may be held between angle clips riveted to the cross girder. The sliding girder is prevented from pulling out of its seat by bolts with check nuts, which pass through the fixed end of the next girder, the web of the cross girder, and then through the end stiffeners of the

sliding girder. Another style of pocket which answers the same purpose is shown in Fig. 19.

A rather unique style of expansion joint, Fig. 20, is obtained by fastening two angles vertically to the lower half of the cross girder, and placing on the top of them a half round pin about four inches in diameter. In the center of the web of the sliding

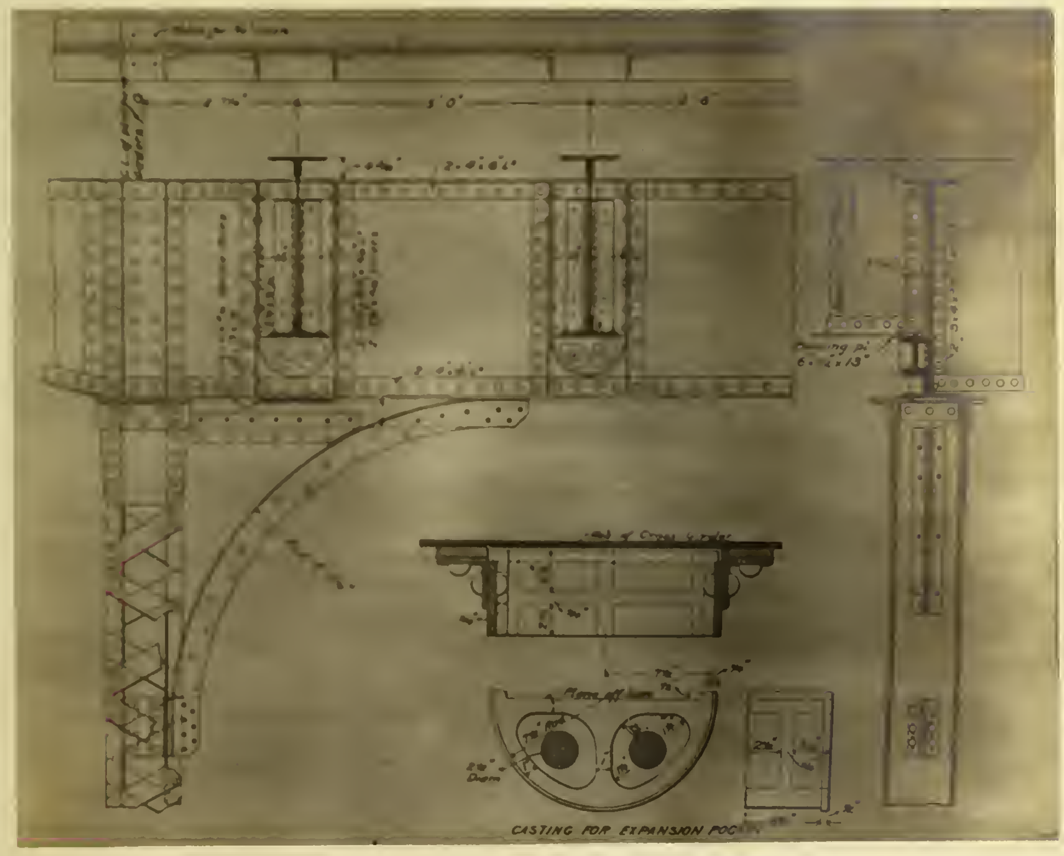

Fig. 19.

girder a hook like extension engages this pin and pulls or pushes it along the top of the upright angles. The chief advantage of this joint is that the sliding girder, under all conditions of bending, always bears evenly on the pin, which in turn sets flat on its supports.

The road which makes no attempt to fix its posts at the top is not much bothered with trouble from expansion joints. Where

the girders rest on the flared top of the column, one end of every other girder is allowed to slip by its fastenings through the use of slotted holes.

The unique European road which has girders with arched lower chords, refered to on page 16 and shown in Fig. 8, easily provides for expansion by having a link and pin connection at one end of the suspended spans. Likewise the road that uses trusses for longitudinals experiences no difficulty from the expansion of metal,

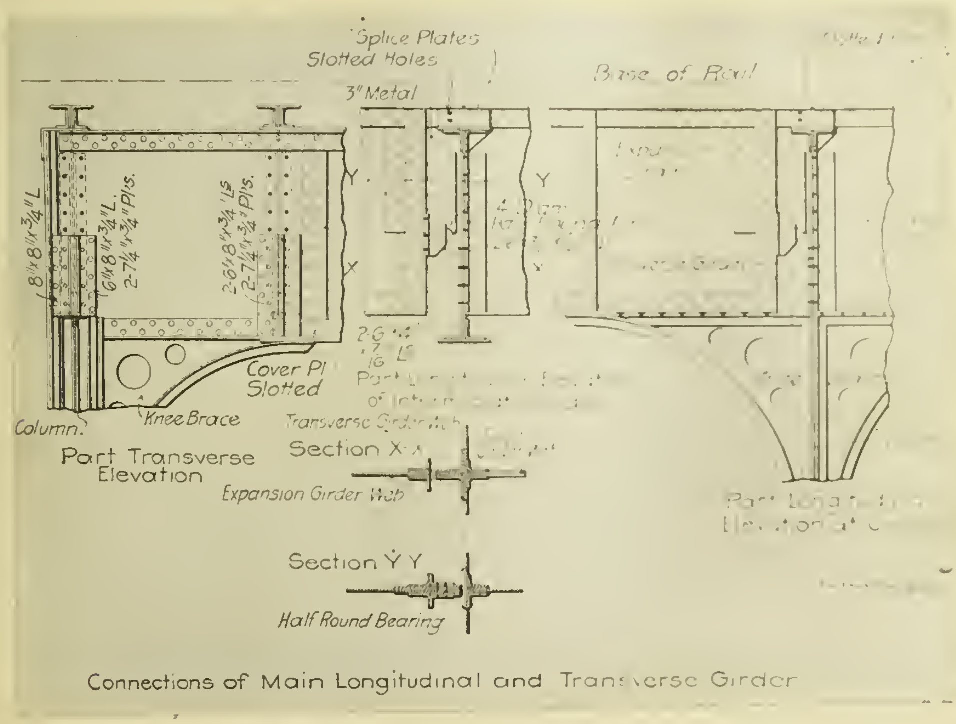

Fig. 20.

since it provides roller bearings under one end of every truss.

BRACING.

Many elevated railways are laid out in the streets, and are required by ordinance to block the thoroughfare as little as possible; and therefore hardly any vertical bracing can be used. The small headway below the longitudinals, generally limited to fourteen or sixteen feet by the cost of columns, does not allow room for

any extensive stiffening systems under the tracks; and therefore the structure depends on the stiffness of its columns for rigidity.

Except on the roads which make a special effort to transmit the horizontal thrust of trains directly to the ground, vertical bracing is limited to knee-braces, sway bracing, and to braces that relieve the cross girders of some of the horizontal thrust. The use of knee-braces has been discussed on page 30. If they are used at all they should be of heavy construction and should be securely riveted to the column and to the girder. Sway bracing as used in elevated roads is very similar to that used in ordinary railroad work. Cross frames are placed at the fourth points, or at the third points of the girders, their chief duty being to prevent the longitudinals from swaying laterally. Often it is necessary to place the columns on the curb line, and in this case a long cross girder is needed to span the distance. The thrust of the longitudinals against this girder tend to bend it laterally, and consequently introduce torsion in the column. In order to prevent this, struts are attached to the column on a level with the top and the bottom of the longitudinal girder and run out diagonally to connect with the flanges of the girder at a panel point of the lateral system. These struts take up the thrust of the track girders and transmit it directly to the top of the column, thereby greatly relieveing the cross girder of lateral strain.

Horizontally an elevated road is quite stiff, due to the lateral systems which brace the girders. These systems may be either the Warren type, or a double system of cancellation. At curves where great strains come on these systems from the centrifugal force, they should be increased in size and if necessary the

supporting columns should be made larger and stronger.

FLOORS.

It has been the general custom in American practice to adopt open floors for elevated roads. They are very similar in construction to the floors used in ordinary railroad bridges or trestles. The ties are fastened to the upper flanges of the longitudinal girders by hook bolts, and sometimes they are also notched to fit down over the flanges. Usually they are about 6x8 inches and are set on from 14 to 16 inch centers. The open spaces between the ties allow the passage of light so that the area under the structure is not greatly darkened.

European practice is inclined to the use of solid floors in elevated-road construction. If these floors shut off some of the light, they also shut off water, sparks, and falling objects; the use of a light colored paint making up partially for the open floor. The first European road used an iron floor known as the Hobson Arch Plate System. Through girders were used, and T bars spanned the distance between the girders at intervals of 2 feet 6 inches. The bars of the Ts extended upward, and their flanges bore on the lower flange of the track girders. Arched plates that had a rise of twelve inches spanned the space between the T bars, and supported the track. Later improvements filled the cavities between the haunches of the arches with gravel and placed longitudinal wooden stringers between the rails and the plates.

Roads which use deck girders have also used solid floors. In these cases either arch or trough plates are sprung between the floor beams and support the ballast either directly or upon a layer

of concrete. The concrete is kept from being racked loose by the use of projecting angles or wire fasteners, while at expansion joints the opening is protected by a steel plate. The ballast is kept in line by the use of dams or ridges in the concrete, and on grades it is kept from creeping by the same means. One difficulty in the use of concrete floors is to obtain proper drainage. Snow has given no trouble, and when it melts it is taken care of by drains which run along the bottom of the depressions and empty through special drips, which prevent the formation of icicles, into drains which reach the sewer at the columns. When concrete is used the water which seeps through is caught on the plates and is gathered in depressions from which it passes into the drains.

NOISE.

Much attention has been paid in recent years to the prevention of noise on elevated roads. The cause of the excessive noise is the vibration of passing trains that is transmitted to the metal beneath. The structure may be prevented from vibrating by being made of heavier sections, which is hardly practicable; or it

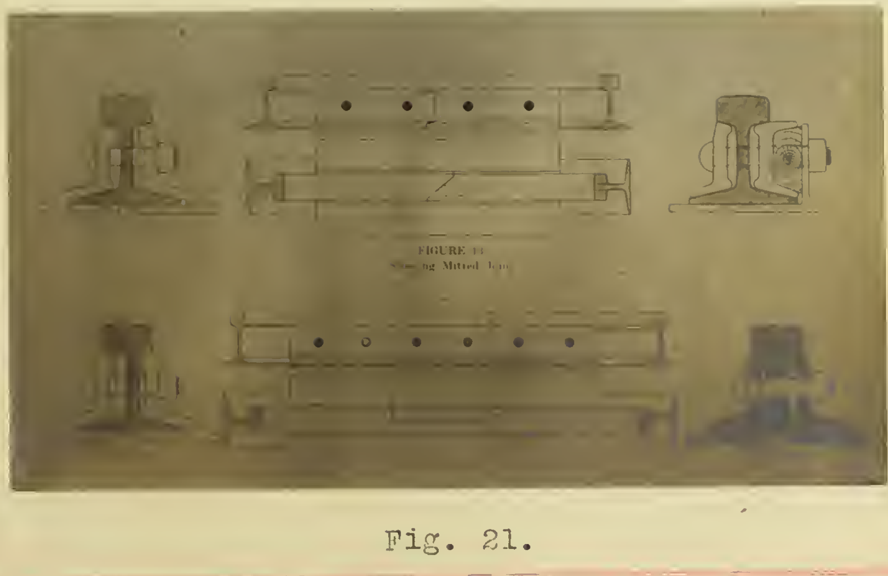

Fig. 21.

can be weighted down by a heavy floor, which method has been the most successful. Many other attempts and experiments have been made, but they have all resulted more or less in failure. Padding the rails with lead, felt, asphalt, and such materials have proved to be useless. Surrounding the rails with gravel in boxes, or encasing the ties in boxes of sand and similar methods have been without much success. Car wheels have been filled with wood, although

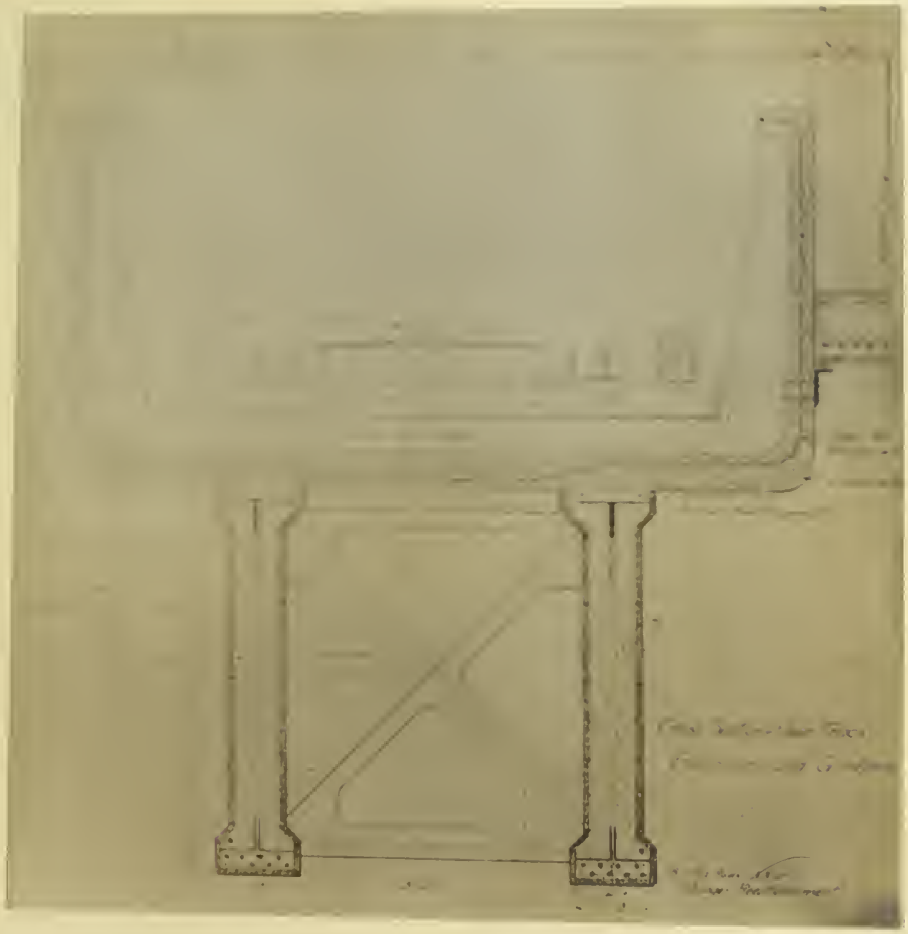

Fig. 22.

wood centered wheels have not been used for fear they would not stand the strain of the motors and braking. Little effect is noticed from the use of mitre rail joints, or even scarf joints which require a special rail section with eccentric webs so that they may overlap their full section at the joint, see Fig. 21. Some little

success attended a scheme which muffled the under side of a steel floor with cork blocks, the construction however is difficult and expensive. It is now proposed to enclose the track and a space above it up to the body of the car between two walls, as is shown in Fig. 22, which will confine the noise or reflect it upward.

The best results have come with the use of ballast on concrete or steel floors. This construction is heavy and therefore does not give forth such a rattling sound as comes from the all-metal structure. The use of these solid floors does not require a heavier structure than is ordinarily used, because the dead load is but a comparatively small factor in the stresses which come on the structure. Of course the use of masonry arches, or of masonry retaining walls with the necessary earth filling, would give an almost noiseless road, the hum of the motors and the click of the wheels alone being audible.

TRACK.

Steam locomotives are no longer used on elevated roads, so that all tracks are now equipped for electric traction. Today the third rail system is in universal use, the trolley having been tried in but one case. A distinctive feature of elevated-road track systems is the conduit or cable box which contains the feeder lines. This box is placed between the tracks and near the center of the structure, the top serving as a walk for employees.

One road for a time had its rails directly on the metal of the structure itself; but this is no longer the case however. The timbers now in use under the rails may be either the cross tie, which is the common practice, or longitudinal wooden stringers,

which are sometimes used. In the open floor systems the timbers last very well, one road built about twelve years ago now has eighty per cent of the original ties still in place and giving good service, only from five to six per cent having to be replaced yearly. Treated ties have been used; but since the ordinary tie gives such good service, the extra cost and the interest on this amount more than pay for the new timbers and the cost of renewals, and therefore it is found to be unprofitable to use the preserved wood. Painted ties were tried, but rotted quite fast because the paint seemed to keep in the moisture. It is a rather expensive undertaking to renew ties on an elevated road, since the trains run on such short intervals, and because all the work has to be handled from the track itself, hence every precaution is taken in the design of the track system to make tie renewals an easy matter. Superelevation of the outer rail on curves may be attained in two ways: either the beveled tie is used, or blocks are inserted under the outside rail. The former method is the more expensive, but gives the better results.

The T rail section is in common use for elevated-road tracks. The rails are set on standard gauge, average about 85 pounds per yard, and are bonded together at the ends so that the track rails form a return circuit for the current from the cars to the power house. The wear on the rails is excessive at the curves, because of the heavy traffic, and because of the short radius that is generally used. The use of tie plates is now becoming quite common, and the best types of bridge joints are now used to connect the rails. Common railroad spikes or screw bolts may be used to fasten the rails to the track timbers.

The special track work on an elevated road is of the high-

est type of construction for this work. The greatest care is necessary because a derailed truck, or a collision might be the cause of the cars being thrown from the structure, which would be a very serious matter. All points of danger are protected by interlocking plants, and the signal systems are of the best styles and are very complete. The track layout has to be quite compact, because the space on the structure is rather precious, thus affording some rather interesting problems in cross-overs, turnouts, and crossings. Unless it is absolutely impossible to do otherwise, grade crossings are avoided, the road which needs the crossing being required to pass overhead.

Heavy longitudinal timbers are often placed on both sides of each rail, and always on at least one side, to act as guards to prevent derailed trucks from leaving the structure. On curves the inside timber is often replaced by steel rails which serve the same purpose, and are better adapted to withstand the wear. These guard rails are bolted through every third or fourth tie, and add great rigidity to the track system. On these bolts cup washers are sometimes used to prevent projections which may trip employees while walking on the track; but their value is questioned, because they are a starting point for decay in the timbers.

The third or conductor rail is usually placed outside of the track on the side nearest to the center of the roadway, although in one case it was placed between the rails on the center line of the track. The conductor rail is above the track rails, and is insulated from them; and it is generally of about the same weight as the traction rails.

As a rule the grades are quite light, nevertheless the roads follow to a certain extent the ground line of the country passed over. Some recent improvements have introduced the use of humps at the stations. These would seem to be an excellent device for the quick starting and stopping of trains; but the authorities say they are not of sufficient grade (1.25%) to be effective, having been put in primarily to give headroom under the structure for a station. Probably, however, these humps will cause some saving in brake shoes.

STATIONS.

The stations on an elevated road should not be too close together, because these roads can only attain their end as a means of rapid transit by making both fast and long runs between stops. The more stations a road has the more territory it serves, because passengers can then afford to expend their energy in walking in directions crossing the line instead of walking parallel to the road; in spite of this however the best paying stations on a particular road are one half mile apart, thus showing that the public is willing to spend a few moments in walking to the train if it can thereby save part of the time otherwise spent on the cars.

There are two possible locations for station buildings: on the ground or on the structure. When the road owns a private right-of-way, it is usually placed on the ground beneath the structure, so that the passengers going in either direction may be served by the same ticket seller, the building being but an entrance to the stairs that lead to the platform above. Buildings on the structure may be either island or side stations. The former, as in Fig.23,

requires but one building, while the latter necessitatie two, thus doubling the original cost and also the cost of maintenence, attendants, light, heat, and so forth. Island stations however require the extra cost of widening the structure in their locality, which is very difficult in city streets, where such elevated stations are generally used, because there is no room for them on the ground.

Fig. 23.

Buildings on the ground are usually of brick or stone, while those on the structure are made of a wooden or steel frame covered with corrugated metal. They contain the ticket office and waiting room, and in addition usually a news-stand and toilet rooms. The interiors are usually neatly though plainly finished in wood and plaster.

Platforms may, like the station, be of the island or side type. They are raised above the track to a level with the car floor. Passengers are prevented from falling off by the use of hand railings on all except the track side, and are protected from the weather by a canopy supported by columns. On one Eropean road the stations, no two of which seem to be architecturally alike, have

their platforms enclosed by walls which are largely of glass; and also have the unusual feature of a roof completely spanning both platform and track, thus making one large waiting room, see Fig. 24. On this road the stairs too are enclosed from the weather and are free from turn-stiles; and tickets are sold by vending machines, some of which sell four kinds of tickets and make change.

Fig. 24.

Stairs are the bug-bear of users of elevated roads. Electrical moving-stairways, or escalators, have been tried; but are too costly to come into general use. When the building is located on the ground the stairs lead up from it with one turn and landing to the center of the platform above. When the station building is on the structure, or if the exit stairs do not pass through the station building below, there are two locations for the stairs: they may run from the edge of the platform and at right angles to it into the street below, or they may pass down parallel to the structure into the street. The former scheme cuts up the platform the least, but

is sometimes the cause of damage suits from property owners. Cross passages may be provided under the track at stations to make connections between the platforms at each side of the railway, thus relieving passengers of the necessity of having to pass busy crossings.

Loops are much better than " dead-house" terminals. They take more room and are more expensive to build, but there is a continual entrance and departure of trains that is capable of handling an immense traffic. They also give a large number of points at which passengers may leave the train, thus affording them an opportunity of easily and quickly reaching their place of business.

ERECTION.

After the foundations have been completed the columns are erected, sometimes by a gin pole on a wagon, and sometimes by derricks on the end of the completed structure. The erection of girders may be accomplished by a traveler which uses the flanges of the erected girders as running rails, and which is known as an overhead traveler; or they may be erected by a traveler which spans the completed structure and runs on rails placed upon the ground one on each side of the structure, and which is known as a striding traveler. The most unique method used was that in which an erection shop was placed at one end of the road and where the whole span, solid floor and all, was riveted up complete, and was placed on cars that ran on the finished structure, and was hauled to its place at the end of the work, where it was seated on the columns by a gantry crane running on the ground, see Fig. 25. The columns had been previously set with a gin pole.

After the steel is in place the floor and tracks are put on, and the structure is painted, and when the electrical equipment and staions are in place, the road is ready for operation.

Fig. 25.

C O S T .

An elevated road is built by private capital, and as usual in such cases the least expensive structure that will serve the purpose has to be put up in the best possible manner. At best these properties are very expensive, costly to build and costly to maintain, being in reality a continuous bridge miles in length. They occupy an intermediate position in cost of construction between underground and surface lines. It is easier to interest capital in their construction than in underground roads, because they involve fewer contingencies than the latter, and therefore the cost can be estimated beforehand with reasonable accuracy. Investors enter the project with the hope of obtaining proper returns; but whether such a road will pay or not depends on its location, the volume of business, the management, and the amount of capital invested. Such roads should be placed in a region that is but sparsely settled at the time construction is going on, but which is bound to become a populous part of the city in the course of a few years. They should not try to compete with opposition that is too strong, as for example the suburban line of a steam railroad. There is no opening in a district until the average passenger is over thirty minutes from his place of business by the best existing lines. The operating expenses on a well managed road under favorable conditions are 60% of the gross earnings, and computations have shown that an eight mile road needs at least 55,000 passengers daily to pay expenses.

The recent subway construction in New York, which was put

in under rather trying circumstances, cost about $3,000,000 per mile. The following somewhat itemized account is the average of several elevated roads owning private right-of-way, which are therefore among the more expensive class of these properties. It was prepared by Mr.G.T.Seeley, Illinois '99, who has been interested in this work for some years, and probably the following figures have never before been published.

Analysis of Cost of Elevated Railways.

	Cost per mile.
Structure, double track structure including station metal, 1,200 lbs. per lin. ft. at say $0.035 erected and painted. - - - - - - - - - - - - - - - - -	$222,000
Foundations, average 5 per 100 ft. at $100. each. - - -	26,400
Stations, average $2\frac{1}{2}$ per mile at $13,000 each.- - - - -	32,500
Track System, $6.00 per lin. ft. of double track. - - -	31,680
Engineering and Superintendence.- - - - - - - - - - - - -	25,000
Total for Elevated Structure. - - - - - - - - -	$337,580
Cars, 25 per mile at $8,000 each. - - - - - - - - - - - -	$200,000
Power House, 35 K.W. per car at $125.00 per K.W. - - -	109,260
Third Rail, 5,280 ft. at $0.50 per ft. - - - - - - - - -	2,640
Feeders, average 8,000,000 C.M. at 3 lbs. per 1,000,000 C.M. per ft., at $0.20 per pound.- - - -	25,400
Yards and Shops, say cost $200,000 for 8 miles. - - - -	25,000
Signals and Interlocking. - - - - - - - - - - - - - - - -	3,000
Total for Elevated Structure and Equipment. -	$702,880
Right of Way. -	$700,240
Engineering and Superintendence, secureing R. of W. - -	350,000
Administration and Legal Expenses.- - - - - - - - - - - -	25,000
Interest during Construction, $1,000,000 at 4% for 2 yrs.	80,000
Total for All Causes. - - - - - - - - - - - - - -	$1,858,120

The account below which is not as complete as the one previously shown, is taken from the report of an engineer on the construction of a branch line of an eastern road that runs above a street. The length of the structure was 3.22 miles.

Cost of ironwork per mile. - - - - - - - - - - - - - - -	$184,423
Cost of foundations per mile including bolts. - - - -	18,647
Cost of double track including labor and material.- -	43,248
Cost of stations averaging 3 per mile.- - - - - - - - -	38,819
Engineering. -	9,934
Total. - - - - - - - - - - - - - - - - - -	$295,071

Elevated-road building seems to be slightly cheaper in Europe than in this country. The roads of Berlin cost including land about $1,150,000 per mile, while those of Paris cost $925,000 per mile. The following figures have been gathered from reports on the surface traction systems of a large American city.

Cost of Cable Roads.

An average of 34.75 miles of single track.

Item.	Cost per Mile of Single Track.
Track, cables, etc.- -	$86,200
Cars, 22 per mile at $1,200 each. - - - - - - - - - - - -	26,400
Paving. -	11,000
Power Plants. -	27,400
Land and Buildings. -	8,480
Total Cost per Mile of Single Track. -	$159,480
Total Cost per Mile of Double Track. -	$318,960

Cost of Electric Roads.

An average of 185.25 miles of single track.

Item.	Cost per Mile of Single Track.
Track, overhead trolley. etc. - - - - - - - - - - - - - -	$25,600
Cars, 5.4 per mile at $2,450 each.- - - - - - - - - - - -	13,200
Paving. -	10,000
Power Plants. -	5,400
Land and Buildings. -	8,480
Total Cost per Mile of Single Track. -	$62,680
Total Cost per Mile of Double Track. -	$125,360

C O N C L U S I O N .

Elevated roads are today in the foremost rank of rapid transit systems. A great many complaints have been made against them; for example,(1) their unsightliness, which may be remedied by the addition of architectural ornaments at a nominal cost; (2) their noisiness, which can be lessened by the use of solid floors and ballasted track; and (3) their darkening effect on the street below, which is overcome to a certain extent by frequent coats of light colored paint. In spite of these objections these roads have been recently adopted into the traction systems of several cities. Whether they will find places in other new fields is a question that the future will answer; but it is certain that the existing roads will build many branches and extensions into the surrounding populous territory of the cities in which they are located, thus doing a great deal to distribute their benefits among a larger number of people.

The material which is set forth in the foregoing thesis has been gathered from personal observation in Chicago, and from reading many articles scattered through general engineering literature and technical periodicals. No book has ever been written on this subject, therefore the author has had no precedent to follow. He wishes to acknowledge his obligations to Mr.G.T.Seeley of the Chicago South Side Elevated Ry.Co. for several interviews, and also for the use of a manuscript article which he had prepared on the subject. The author is indebted also to Mr.B.J.Arnold for material

taken from his report upon "Reducing the Noise of the Union Elevated Railway of Chicago." Undoubtedly the best collection of material on the subject of elevated roads is the paper by Mr. J. A. L. Waddell and the discussions that it called forth, which are recorded in Volume 37 of the Transactions of the American Society of Civil Engineers. This compilation of the opinions of the best elevated railroad men of the country has been an especially great help to the writer of this thesis.